Journal of Forensic and Legal Medicine 18 (2011) 246–252

Contents lists available at ScienceDirect

Journal of Forensic and Legal Medicine

journal homepage: www.elsevier.com/locate/jflm

Clinical practice

Gender determination from hand bones length and volume using multidetector computed tomography: A study in Egyptian people

Ghada A. Eshak MD Assistant professor of Forensic Medicine & Clinical Toxicology [a,*], Hala M. Ahmed MD Assistant professor of Forensic Medicine & clinical Toxicology [a], Enas A.M. Abdel Gawad MD Lecturer of Radiodiagnosis [b]

[a] *Forensic Medicine and Clinical Toxicology Department, Faculty of Medicine, Minia University, Egypt*
[b] *Radiodiagnosis Department, Faculty of Medicine, Minia University, Egypt*

ARTICLE INFO

Article history:
Received 27 February 2011
Accepted 20 April 2011
Available online 20 May 2011

Keywords:
Forensic anthropology
Sex determination
Discriminant function
MDCT
Egyptians

ABSTRACT

Determination of sex from incomplete skeletal and decomposing human remains is particularly important in personal identification. Measurements of hand bones length have been shown to be sexually dimorphic in many nationalities. Since the validity of discriminant function equation in sex determination is population specific; the purpose of this study is to assess sex from the hand bones length in a contemporary Egyptian population using data derived from both multiplanar (two-dimensional) and volumetric (three-dimensional) reformatted images of multidetector CT to derive special equations for sex determination in Egyptians. One hundred and twenty two Egyptians (60 males and 62 females) with mean age of 24.1 ± 4.4 were included. An independent samples student's *t*-test and discriminant function analysis were done. Results indicate existence of length differences between the sexes. Males presented with significantly greater mean values than females for distal phalanges of all fingers, 1st and 3rd proximal phalanges and all metacarpal bones measured by 2D images. Metacarpals, proximal phalanges and distal phalanges are sexually dimorphic with accuracies of 80%, 76.6% and 80% respectively. Three-dimensional volume-rendered reconstructed images of metacarpals give more accurate results (92.9%) in correct sex determination when compared with 2D images. From the forensic standpoint, the usefulness of this study rests on the identification of sex among Egyptian based on length and volume differences observed on MDCT examination.

© 2011 Elsevier Ltd and Faculty of Forensic and Legal Medicine. All rights reserved.

1. Introduction

Identification is the mainstay of any forensic investigation, whether it is of the suspect from the physical evidence at the crime scene or of the victim from dismembered, mutilated and charred remains.[1] Identification of victims from dismembered human remains has always been a challenge for forensic scientists.[2]

Sex determination is the vital part of identification, which is often required in medico-legal practice.[3] Sex is the first demographic factor that is determined because it reduces the number of possible matches by 50%.[4]

Forensic anthropology is a branch of physical anthropology primarily concerned with the postmortem identification of human remains in a medico-legal context.[5] When an individual hand is recovered and brought for examination, somatometry of the hand, osteological and radiological examination can help in the determination of primary indicators of identification such as sex, age and stature.[6]

Previous studies have shown that the metacarpals are useful for the sex determination of skeletal remnants, but they obtained conflicting results in terms of accuracies that were explained by racial, temporary or populational variances.[7] There have been fewer studies on phalanges for the same purpose. Anatomically short tubular bones have some advantages over other bones in a forensic context. The shafts of long bones often stay intact, but their epiphyses are prone to damage because of the overlying fragile cancellous bone. However, the smaller long bones of the hands often remain complete.[8]

Measurements of the hand bones have been shown to be sexually dimorphic in South African males and females,[9] Turkish,[10] South Indians,[11] Greeks[12] and Athens.[13] Since the validity of discriminant function equation in sex determination is population specific,[14] the aim of this study is to assess the accuracy of sex determination from the metacarpals and phalangeal measurement data obtained from

Abbreviations: kVp, Kilovolt; mAs, Milliampere; FOV, Field of View; MDCT, Multidetector computed tomography; 2D, Two dimension; 3D, Three dimension; MPR, Multiplanar reformation.

* Corresponding author. Forensic Medicine and Clinical Toxicology Department, Faculty of Medicine, Minia University, Egypt. Tel.: +20 106363490.
E-mail address: doctorghadaattia@hotmail.com (G.A. Eshak).

1752-928X/$ – see front matter © 2011 Elsevier Ltd and Faculty of Forensic and Legal Medicine. All rights reserved.
doi:10.1016/j.jflm.2011.04.005

multiplanar (two-dimensional) and volumetric (three-dimensional) reformatted images of multidetector CT and to develop equations for Egyptians that would provide the best way to determine sex. The datasets of the left hand were used as the majority of the population is right-handed and therefore left hand will be less influenced by activity.

2. Subjects and methods

A total of 2318 bones from left hands of one hundred and twenty two right-handed adult Egyptians (60 males & 62 females presented to Radiology department of Suzan Mubarak University Hospital from March 2010 to September 2010) were scanned by multidetector CT examination to detect their length. Cases with skeletal immaturity, fracture, pathological lesions such as congenital and developmental dysplasia, metabolic bone diseases, or surgery, as well as tumors, osteoarthritis and arthritis were excluded from this study. The procedures followed were in accordance with the ethical standards of the responsible committee of Faculty of Medicine, Minia University.

2.1. MDCT protocol for image acquisition

CT studies were performed using a 16-detector CT scanner (BrightSpeed 16; GE Medical Systems) without contrast material. Scanning along the axial axis of the entire left hand including the carpal joint was performed using the following parameters: 120 kVp, 260 mAs, a helical pitch of 0.562:1, 0.8 s scan time, 16 × 1.25 mm detector configuration, 8.8 s total exposure time, 1.25 mm helical slice thickness, and 0.6 mm reconstruction interval with a small FOV. The images were reconstructed using a bone algorithm. The protocol used for scan acquisitions was identical for all patients to avoid technical variations in length and volume measurements.

2.2. Reconstruction and post-processing considerations

For 2D and 3D reconstruction images, the axial source images with a 1.25-mm slice were transferred to an Advantage Workstation (AW) Volume Share 2 (GE Healthcare).

2.3. 1-Two-dimensional reconstruction

Multiplanar reformatted (MPR) images were obtained in coronal plane through the entire left hand with a section thickness of 1.2 mm, and a section reconstruction interval of 1.0 mm. The lengths of all metacarpals and phalanges (proximal, middle and distal) were measured from the midpoint of the base to the distal tip point of each bone by measure distance tool.

2.4. 2-Three-dimensional reconstruction

Three-dimensional (3D) CT images were obtained by using 3D volume rendering technique. 3D reconstruction image of the entire left hand was performed using The Volume Viewer 3.1 which is powerful 3D analysis software which runs at the AW workstation; it enables fast volumetric review of CT datasets. This software creates a 3D volume of slice data that is displayed automatically as volume-rendered (VR) view.

The Paint tool is used to define manually the volume of the 2nd and 4th metacarpal bones which isolated from the original 3D volume of the entire left hand. After their segmentation and isolation, their volumes were calculated by clicking the volume measurement tool and then by clicking the viewport where was the segmented bone, the volume was then displayed automatically on the 3D viewport.

3D volume measurements were performed for only the 2nd and 4th metacarpal bones as a representative example of hand bones to compare its accuracy with that of 2D measurement in correct sex determination. Volume calculation could not be performed for all hand bones because while 3D volume-rendered reconstruction CT images of the entire left hand were obtained automatically and rapidly, isolation of individual hand bones were performed manually and it is time consuming process because of large number of slices produced per examination[15] so we use the second and fourth metacarpals bone only as a separate bone. In this study approximately 400 slices produced per examination.

2.5. Statistical analysis

Data were analyzed using SPSS statistical package version 17. Results were expressed as mean ± standard deviation (SD). Independent samples students *t*-test was performed to establish existence of significant difference between male and female bone lengths. Univariate discriminant function analysis was performed to obtain demarking points for male and female that could be used for fragmentary bones. All measurements were used to select the variable or combination of variables that best discriminates between sexes. Direct analysis of data was performed to develop formulas to allow accurate sex determination from fragmentary remains for Egyptians. A p-value of <0.05 was considered as statistically significant.

3. Results

Age and sex distribution of the studied subjects is shown in Table 1. Males presented with significantly greater mean values than females ($P < 0.05$) for the lengths (2D measurements) of the distal phalanges of all fingers, 1st and 3rd proximal phalanges and all metacarpal bones. (Table 2) (Figs. 1 and 2). Neither the middle phalanges nor the 2nd, the 4th or the 5th proximal phalanges showed significant differences between males and females. The calculated volumes (3D measurements) of the 2nd and 4th metacarpal bones (Figs. 3 and 4) showed significant difference between males and females (Table 3) indicating presence of significant sexual dimorphism in hand measurements of Egyptian people.

The cut off value and the accuracy percentage in correct sex classification for males and females in individual and grouped bones are presented in Tables 4 and 5. A measured value higher than the demarking point classifies an individual as male and a lower value suggests female. Metacarpals, proximal phalanges, middle phalanges and distal phalanges are sexually dimorphic with accuracies of 80%, 76.6%, 70% and 80% respectively, while the volume of metacarpal bones by 3D gave sexual dimorphic accuracy of 92.9%. Tables 6 and 7 show discriminant function analysis for individual and grouped bones.

In our study volumetric measurement of the 2nd & 4th metacarpals are more accurate in correct sex determination when compared with 2D CT measurement with a total accuracy of 92.3% and 71.4% for the 2nd & 4th metacarpals respectively. (Table 8).

The following equation was applied for sex determination from hand bones calculating their score in the discriminant function.

$$\begin{aligned}\text{Df for}(X) = {} & \text{mean of X1} \times \text{dfc1} + \text{mean X2} \times \text{dfc2} + \text{mean X3} \\ & \times \text{dfc 3} + \text{meanX4} \times \text{dfc4} + \text{mean X5} \times \text{dfc5}\end{aligned}$$

Table 1
Descriptive statistics of the subjects by means of age ($N = 122$).

Sex	Minimum	Maximum	Mean	SD
Male ($n = 60$)	18	30	23.3	4.4
Female ($n = 62$)	19.5	30	24.8	4.5
Total ($n = 122$)	18.75	30	24.1	4.4

Table 2
Second dimensional range, mean and standard deviation of hand bones length (mm) in studied subjects ($N = 122$).

Bone			Fingers									
			1st finger		2nd finger		3rd finger		4th finger		5th finger	
			Min	Max	Min.	Max.	Min.	Max	Min.	Max	Min.	Max.
Distal phalanx	Range	M	18	32	14	19	14	20.5	15.5	20.6	13.2	20.5
	Mean ± SD		22.3 ± 3.3		17.3 ± 1.3		17.9 ± 1.7		18.9 ± 1.5		17.1 ± 1.8	
	Range	F	17	22.4	13.6	19	13.9	20	13.7	19	12.6	17.7
	Mean ± SD		19.9 ± 1.6		15.7 ± 1.4		16.5 ± 1.6		16.8 ± 1.6		14.5 ± 1.4	
		T	2.5		3.32		2.5		3.72		4.2	
		P	0.018		0.003		0.018		0.001		0.0001	
Middle phalanx	Range	M	None		20.5	27.2	21.9	31.4	23.9	31.8	15.3	21.4
	Mean ± SD				23.4 ± 1.7		27.9 ± 2.2		26.9 ± 2.5		8.7 ± 2.1	
	Range	F	None		19.7	25.4	23	31.4	23	39.8	14.6	21.1
	Mean ± SD				22.3 ± 1.6		27.4 ± 2.4		25.5 ± 2.3		17.6 ± 2.2	
		T	–		1.8		0.47		0.98		1.39	
		P	–		0.08		0.48		0.10		0.18	
Proximal phalanx	Range	M	26.3	33.9	32.3	44.8	36.6	48.1	28.2	45.6	19.6	36
	Mean ± SD		29.5 ± 2.5		39.4 ± 2.9		43.6 ± 2.8		40.1 ± 4.2		31.9 ± 3.8	
	Range	F	20	32	30	41.5	34.1	46.9	33.1	43.7	23.7	34.7
	Mean ± SD		27.3 ± 3.1		37.1 ± 3.7		41.1 ± 3.5		38.5 ± 2.9		29.8 ± 3.1	
		T	2.10		1.88		2.21		1.17		1.65	
		P	0.05		0.07		0.04		0.25		0.11	
Metacarpals (2D)	Range	M	38.2	50.5	55.2	73.1	52.7	71.5	45.8	63	39	57.6
	Mean ± SD		44.9 ± 3.6		67.7 ± 5.1		64.8 ± 5.7		57.2 ± 6.2		51.5 ± 4.9	
	Range	F	30	46.4	51.1	74.2	48.3	66.9	44	58.5	35.6	55.6
	Mean ± SD		40.2 ± 4.9		62.1 ± 5.4		59.6 ± 4.9		52.6 ± 4.5		46.6 ± 5.2	
		T	3.01		2.932		2.67		1.81		2.65	
		P	0.006		0.007		0.013		0.05		0.013	

S.D: Standard deviation M: Male F: Female MIN.: Minimum Max.: Maximum $p < 0.05$: significant difference.

Where df is degree of freedom, X is the bone, (1,2,..etc.) is the finger number and dfc is the discriminant function coefficient.

From this equation; two values for male and female were achieved; the cut point can be calculated as follows: (male df + females df) ÷ 2; bone length above cut off value; the individual is male and if below; the individual is considered female.

$$\text{Df for distal phalanges(male)} = 22.3 \times 0.206 + 17.3 \times 0.117 + 17.9 \times -0.307 + 18.9 \times 0.223 + 17.1 \times 0.850 = 19.87$$

$$\text{Df for distal phalanges(female)} = 19.9 \times 0.206 + 15.7 \times 0.117 + 16.5 \times -0.307 + 16.8 \times 0.223 + 14.5 \times 0.850 = 16.94$$

$$\text{Cut off point} = (19.87 + 16.94) \div 2 = 18.41$$

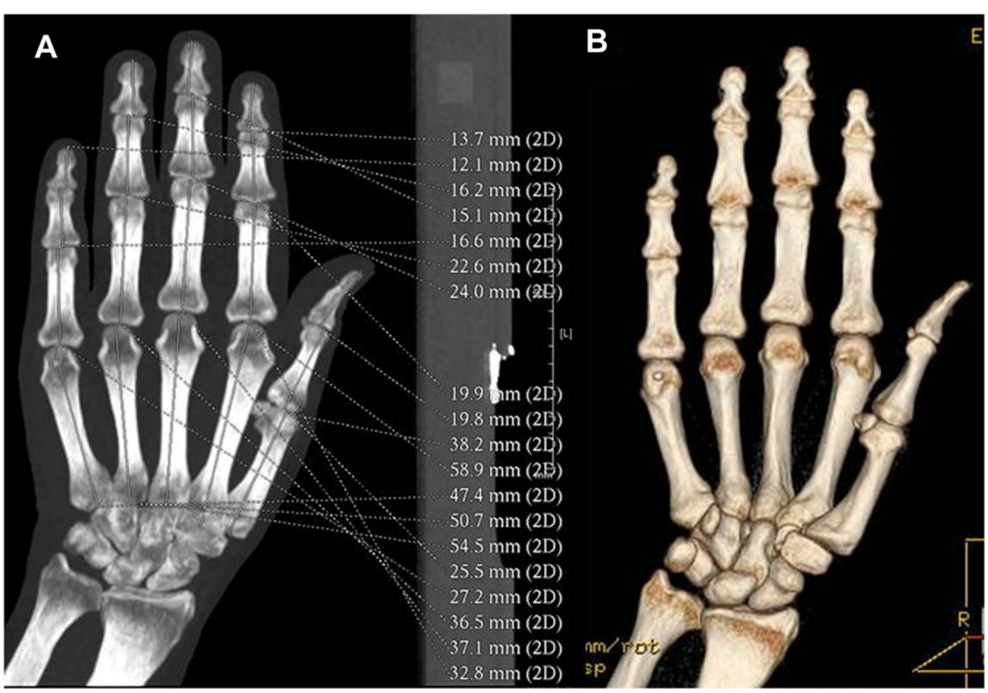

Fig. 1. (A) Coronal Multiplanar Reformatted (MPR) CT image of the left hand of a 30-year-old female shows the 2D measurements of the lengths of the metacarpals and phalangeal bones in mm. (B) Corresponding 3D volume-rendered reconstructed CT image of the hand bones.

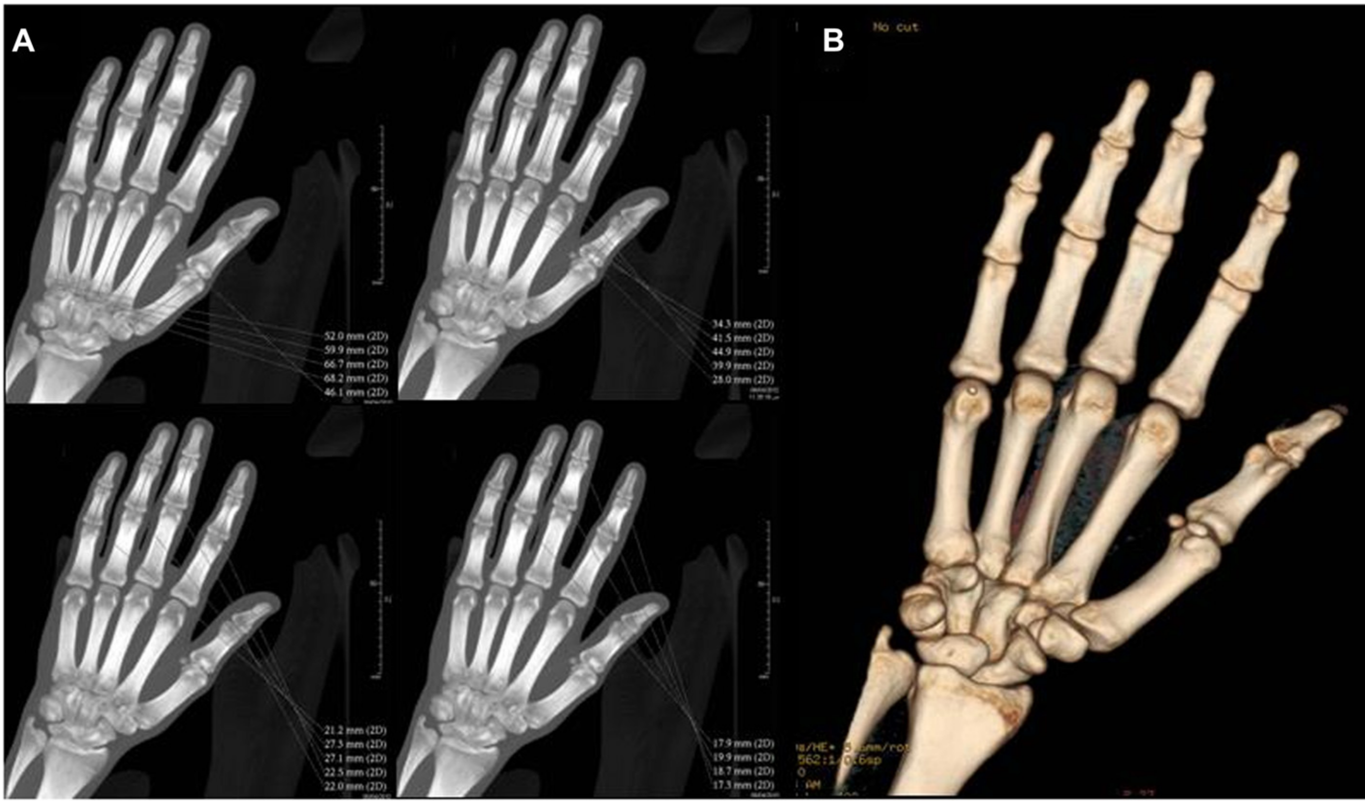

Fig. 2. (A) Coronal Multiplanar Reformatted (MPR) CT images of the left hand of a 20-year-old male show the 2D measurements of the lengths of the metacarpals and phalangeal bones in mm. (B) Corresponding 3D volume-rendered reconstructed CT image of the hand bones.

$$\text{Df for proximal phalanges(male)} = 29.46 \times 0.938 + 39.4 \times -1.339 + 43.60 \times 1.71 + 40.07 \times -0.608 + 31.85 \times 0.193 = 31.217$$

$$\text{Df for proximal phalanges(females)} = 27.32 \times 0.938 + 37.10 \times -1.339 + 41.06 \times 1.71 + 38.51 \times -0.608 + 29.79 \times 0.193 = 28.497$$

$$\text{Cut off point} = (31.217 + 28.497) \div 2 = 59.714 \div 2 = 29.86$$

$$\text{Df for metacarpals(male)} = 44.92 \times 0.513 + 67.68 \times 0.622 + 64.79 \times 0.869 + \times 56.193 \times 1.047 + 51.5067 \times -0.106 = 57.1496.$$

$$\text{Df for metacarpals(females)} = 40.187 \times 0.513 + 62.08 \times 0.622 + 59.61 \times 0.869 + 52.64 \times -1.047 + 46.633 \times -0.106 = 50.9739.$$

$$\text{Cut off point metacarpals} = (57.1496 + 50.9739) \div 2 = 54.06$$

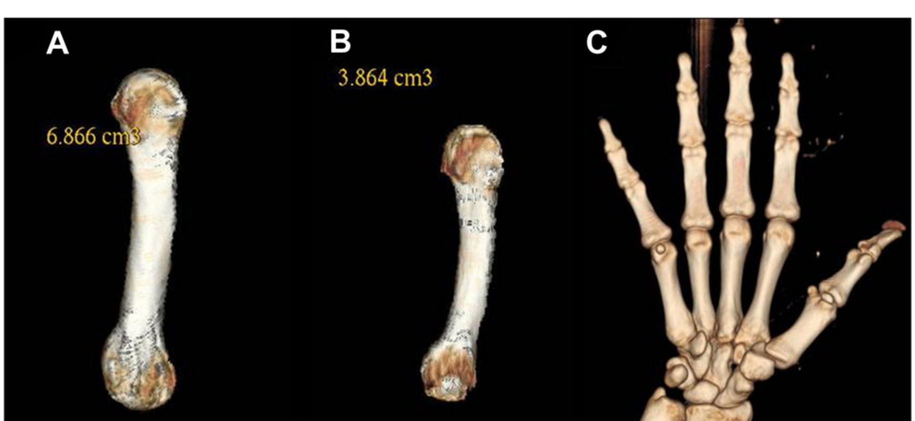

Fig. 3. (A & B) 3D volume-rendered reconstructed CT images of the 2nd (A) and 4th (B) metacarpal bones which separated manually from the original 3D volume (C) of the entire left hand of an 18-year-old female demonstrate the computed volumes of the 2nd (6.866 cm^3) and 4th (3.864 cm^3) metacarpal bones.

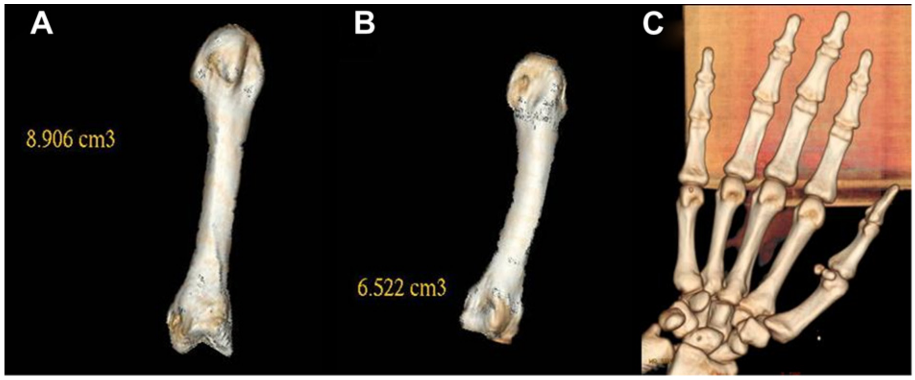

Fig. 4. (A & B) 3D volume-rendered reconstructed CT images of the 2nd (A) and 4th (B) metacarpal bones which separated manually from the original 3D volume (C) of the entire left hand of a 23-year-old male demonstrate the computed volumes of the 2nd (8.906 cm^3) and 4th (6.522 cm^3) metacarpal bones.

Data revealed that the metacarpal length, distal phalangeal length and the length of the first and the third proximal phalanges are the best three variables that can be used together in correct sex determination with a percentage of 90% which is the same result obtained by the three linear measurements together.

4. Discussion

Forensic anthropologists are continually attempting to improve methods of skeletal identification through the development of new methods for determining sex or the fine-tuning of known methods on various parts of the skeleton.[16]

Sex assessment is one of the first essential steps in human identification, in both medico-legal cases and bio-archaeological contexts. Fragmentary human remains compromised by different types of inhumation or physical insults may frustrate the use of the traditional sex estimation methods, such as the analysis of the skull and pelvis. Currently, the application of discriminant functions to sex unidentified skeletal remains is steadily increasing. However, several studies have demonstrated that, due to variation in size and patterns of sexual dimorphism, discriminant function equations are populationspecific.[17]

Several previous studies have addressed the issue of hand for their sex estimation potential, they investigated accuracies of sex discrimination either by measuring hand length,[18,19] by measuring bones length[9,13,20] and by X ray.[21,22]

To best of our knowledge it is the first time to use CT to assess accuracy of sex determination from hand. CT has been used in forensic field for many objectives; for disaster victim identification,[23,24] for distinguishing aspiration into the lungs from airways and for identifying the aspirated material relative to autopsy,[25] for virtual autopsy,[26] for sex determination from sternum and fourth rib,[27] from foramen magnum,[28] from whole cranium.[29] This study employed CT imaging of metacarpals and phalanges.

MDCT represents the latest breakthrough in CT technology. It has transformed CT from a transaxial cross-sectional technique into a truly three-dimensional imaging modality with a variety of clinical applications mainly in musculoskeletal imaging.[30]

Table 3
Three-dimensional range, mean and standard deviation volumes of the 2nd and 4th metacarpals in cm3 in studied subjects ($N = 120$).

Sex		Bone			
		2nd. metacarpal		4 th. metacarpals	
		Minimum	Maximum	Minimum	Maximum
Male	Range	6.2	10.3	4.06	6.5
	Mean ± SD	8.4 ± 1.2		5.1 ± 1.01	
Female	Range	4.69	7.01	3.03	4.73
	Mean ± SD	5.7 ± 0.9		3.7 ± 0.5	
T		4.378		3.161	
P		0.01		0.008	

Table 4
Cut off values (in mm) and accuracy percentage for sex differentiation for individual bone ($N = 122$).

Bone	Cut off values	Accuracy %	Total %
Distal phalanges1	Female <21.12 < Male	Female 80% Male 66.7%	73.3%
Distal phalanges2	Female <16.49 < Male	Female 80% Male 73.3%	76.7%
Distal phalanges3	Female < 17.23 < Male	Female 66.7% Male 80%	73.3%
Distal phalanges4	Female <17.83 < Male	Female 66.7% Male 80%	73.3%
Distal phalanges5	Female <15.785 < Male	Female 86.7% Male 80%	83.3%
Middle phalanges2	Female <22.85 < Male	Female 66.7% Male 60%	63.3%
Middle phalanges3	Female <27.66 < Male	Female 66.7% Male 53.3%	60%
Middle phalanges4	Female < 26.2 < Male	Female 73.3% Male 53.3%	63.3%
Middle phalanges5	Female < 18.18 < Male	Female 60% Male 53.3%	56.7%
Proximal phalanges1	Female < 28.39 < Male	Female 53.3% Male 46.7%	50%
Proximal phalanges2	Female < 38.25 < Male	Female 53.3% Male 66.7%	60%
Proximal phalanges3	Female < 42.33 < Male	Female 53.3% Male 73.3%	63.3%
Proximal phalanges4	Female <39.29 < Male	Female 53.3% Male 66.7%	60%
Proximal phalanges5	Female < 30.82 < Male	Female 60% Male 73.3%	66.7%
Metacarpal1	Female <42.55 < Male	Female 66.7% Male 80%	73.3%
Metacarpal2	Female <64.88 < Male	Female 73.3% Male 80%	76.7%
Metacarpal3	Female < 62.5 < Male	Female 66.7% Male 73.3%	70%
Metacarpal4	Female < 54.42 < Male	Female 73.3% Male 60%	66.7%
Metacarpal5	Female <49.07 < Male	Female 73.3% Male 80%	76.7%
Metacarpal2 3D	Female <7.09 < Male	Female 100% Male 85.5%	92.9%
Metacarpal4 3D	Female <4.43 < Male	Female 57.1% Male 85.7	71.4%

Table 5
Cut off values (in mm) and accuracy percentage for sex differentiation for grouped bones ($N = 122$).

Bone	Cut off values	Accuracy %	Total %
Distal phalanges	Female <18.41 < Male	For females 80% For males80%	80%
Middle phalanges	Female <22.9 < Male	For females 73.3% For males 66.7%	70%
Proximal phalanges	Female <29.86 < Male	For females 80% For males 73.3%	76.6%
Metacarpals (2D)	Female <54.6 < Male	For females 73.3% For males 86.7%	80%
Metacarpals (3D)	Female <7.04 < Male	For females 100% For males 85.7%	92.9%

The main advantages of MDCT are the enhanced speed of scan acquisition and the high spatial resolution because of the thin collimation. This facilitates precise timing of multiphasic imaging and multiplanar reformations (MPR) using several reformation techniques, such as maximum intensity projections (MIP), volume rendering, and curved planar reconstructions (CPR).[31]

MDCT with various multiplanar reconstructions have contributed significantly for obtaining an excellent anatomic depiction of bones devoid of artifacts.[32] In this study coronal MPR allow better anatomical delineation of the hand bones with subsequent more accurate measurements of their lengths.

The length of distal and middle phalanges for both Egyptian males and females were more than the measurements taken by Banu et al. (2009)[9] on a sample of Turkish people, while those of proximal phalanges and metacarpals were less than them. This difference can be the result of genetic factors, environmental factors affecting growth and development (nutrition, physical activity, pathological, etc.), and the interaction of previous factors.[14,33]

Independent samples *t*-test was done for all males and females samples, the results revealed that there was significant difference between male and female metacarpals, distal phalanges and first and third proximal phalanges only but not with middle phalanges, these results are in agree with Tanuj and Kewal, (2011).[34]

By discriminant function analysis; Egyptian metacarpals, the first and the third proximal phalanges and distal phalanges show sexual dimorphism which is explained by differences in body size between both sexes and the fact that men and women do different things, to different degrees.[35] Moreover, Male metacarpals have larger dimensions than females ones, which could be due to the mechanical response of the bone owing to the greater muscular demand of males. Such a hypothesis would be supported by the work of DiBennardo and Taylor,[36] and Ruff,[37] who suggested that epiphyseal dimensions are more conditioned than the longitudinal variables because of functional stress and physical activity. Black,[38] however, offered an alternative, proposing that during development, males would generate a larger amount of cortical bone and that when they reach adulthood their bones would have a rhythm of osseous remodeling different from that seen in female bones.

The average accuracies of classification found in this study are comparable to those found by others,[9,20] Case and Rose[13] investigated the length of metacarpals and phalanges for sex determination in 259 individuals (123 females, 136 males) consisting of White Americans of European descent and European immigrants. Their results showed that the phalanges were better than the metacarpals for estimating sex and that the ability of the phalanges to correctly determine sex seems to improve in a distal direction. They achieved 85.7% accuracy with the use of distal phalanges, 80.8% with the use of middle phalanges, 80.8% with the use of proximal phalanges and 79.6% with the use of metacarpals. As regard the results of our study; it achieved 80% accuracy with the distal phalanges, 70% with the use of middle phalanges, 76.6% with the use of proximal phalanges and 80% with the use of metacarpals by 2D CT measurements.

Similarly; Scheuer and Elkingto[39] obtained 74%–94% accuracy in the correct determination of sex from metacarpals and the first phalanx of British Whites, and the first metacarpal was found to give the highest degree of accuracy in identifying sex but it disagree with our study which proved that the second and fifth metacarpals have the highest accuracy 76.7% than the remaining metacarpals. Also the distal phalanges, the first and the third proximal phalanges have the higher accuracy in sex identification. The results of this study correlate with the study of Falsetti[40] who tested the populational differences through analyzing three samples (212 individuals) from the Terry Collection consisting of European Americans, African Americans both Black and White and 33 individuals from the Royal Medical School, UK. He generated linear discriminant functions based on five measurements of five metacarpals and he concluded that the functions of MC2, MC4 and MC5 could provide an alternative method for sex assessment.

Table 6
Results of the discriminant function analysis for grouped bones of the left hand for Egyptians.

	Bone	Eigenvalue	Canonical correlation	Wilks lambda	Chi-square	Significance
2D	Distal phalanges1	0.224	0.427	0.817	5.548	0.019
	Distal phalanges2	0.373	0.521	0.728	8.723	0.003
	Distal phalanges3	0.225	0.428	0.816	5.578	0.018
	Distal phalanges4	0.495	0.575	0.669	11.057	0.001
	Distal phalanges5	0.638	0.624	0.610	13.571	0.000
	Middle phalanges2	0.116	0.322	0.896	3.01	0.083
	Middle phalanges3	0.019	0.135	0.982	0.505	0.477
	Middle phalanges4	0.103	0.305	0.907	2.686	0.305
	Middle phalanges5	0.069	0.254	0.936	1.828	0.176
	Proximal phalanges1	0.158	0.369	0.864	4.027	0.045
	Proximal phalanges2	0.127	0.335	0.888	3.282	0.070
	Proximal phalanges3	0.174	0.385	0.852	4.413	0.036
	Proximal phalanges4	0.049	0.216	0.954	1.308	0.253
	Proximal phalanges5	0.097	0.298	0.911	2.555	0.110
	Metacarpal 1	0.322	0.494	0.756	7.683	0.006
	Metacarpal 2	0.307	0.485	0.765	7.365	0.007
	Metacarpal 3	0.254	0.450	0.797	6.231	0.013
	Metacarpal 4	0.116	0.323	0.896	5.029	0.05
	Metacarpal 5	0.250	0.447	0.800	6.143	0.013
3D	Metacarpal 2	1.597	0.784	0.385	10.975	0.001
	Metacarpal 4	0.832	0.674	0.546	6.965	0.008

Table 7
Results of the discriminant function analysis for grouped bones of the left hand for Egyptians.

Bone	Eigenvalue	Canonical correlation	Wilks lambda	Chi- square	Significance
Distal phalanges	0.733	0.650	0.577	14.027	0.015
Middle phalanges	0.116	0.322	0.896	3.01	0.083
Proximal phalanges	0.287	0.472	0.777	6.430	0. 267
Metacarpal bones (2D)	2.811	0.859	0.262	34.116	0.005
2nd.&4th. metacarpal bones (3D)	1.597	0.784	0.385	10.499	0.005

Table 8
Comparison between accuracy of the length (2D) and volume (3D) of the 2nd and 4th metacarpal bones in sex determination ($N = 122$).

		Accuracy%		Total % of accuracy	Significance
		Male	Female		
2nd metacarpal	Length	80%	85.7%	76.6%	t 2.932
	Volume	73.3%	100%	92.3%	P 0.007
4th. Metacarpal	Length	60%	73.3%	66.7%	t 4.378
	Volume	57.1%	85.7%	71.4%	P0.004

The percentage of misclassification in sex determination (7.1% - 30%) can be explained on two bases constant and inconstant misclassification; constant “wrong classified cases” (i.e. males of reduced dimensions or very strong musculature females) and inconstant, cases that are included in one sex in some functions and other times in others slender males and robust females with body dimensions similar to the average of each sex.[36]

In our study we used volume-rendered technique to obtain 3D reconstruction CT images and to estimate the volumes of hand bones. This technique proved by others[41] to be a flexible, accurate 3D imaging technique that can help the radiologist more effectively interpret the large volumes of data generated by modern CT scanners. 3D volume rendering technique also can eliminate the vast majority of streak artifact and clearly delineates the fine anatomic details and morphology of the bones, and bone fragments.[41,42] Kalayci[43] also used the 3D reconstruction images of phalangeal and metacarpal bones to provide basic morphometric information regarding the hand bones of judo players and sedentary men. Our results proved that the accuracies of 3D volumetric measurements in sex determination were 92.3% and 71.4% for the 2nd & 4th metacarpals respectively which were significantly higher than accuracies obtained by 2D measurement of their lengths.

5. Conclusion

Metacarpal bones and distal phalanges are the most suitable bones for accurate sex determination. Multidetector computed tomography is useful in making reliable measurements of hand bones which can be used with a fair degree of accuracy to determine the sex of unknown individual. An analysis with multiple variables yields better classification accuracies than using single variable.

Conflict of interest

The authors declare that there are no conflicts of interest with any institution or organization.

Funding

None declared.

Ethical approval

This work was approved by ethical committee of Faculty of Medicine, Minia University, for human experimentation.

References

1. Agnihotri AK, Purwar B, Googoolybe K, Agnihotri S, Jeebun N. Estimation of stature by foot length. *J for Leg Med* 2007;**14**:279–83.
2. Jasuja OP, Singh G. Estimation of stature from hand and phalange length. *J Indian Acad Forensic Med* 2004;**26**:100–6.
3. Robling AG, Ubelaker DH. Sex determination from metatarsals. *J For Sci* 1997;**42**(6):1062–9.
4. Loth SR, Iscan MY. Sex determination. In: Siegel JA, Saukko PJ, Knupfer GC, editors. *Encyclopedia of forensic sciences*. London: Academic Press; 2000.
5. Sanli SG, Kizilkanat ED, Boyan N, Ozsahin ET, Bozkir MG, Soames R, et al. Stature estimation based on hand length and foot length. *Clin Anat* 2005;**18**:589–96.
6. Williams TJ, Pepitone ME, Christensen SE, Cooke BM, Huberman AD, Breedlove NJ, et al. Finger-length ratios and sexual orientation. *Nature* 2000;**404**:455–6.
7. Zanella VP, Brown TM. Testing the validity of metacarpal use in sex assessment of human skeletal remains. *J for Sci* 2003;**48**:17–20.
8. Rosing FW, Graw M, Marré B, Ritz- Timme S, Rotzscher K, Schmeling A, et al. Recommendations for the forensic diagnosis of sex and age from skeletons. *Homo J Comp Hum Anat* 2007;**58**:75–89.
9. Navsa N, Steyn M, Iscan MY. *Sex determination from the metacarpals in a modern South African male and female sample*. Pretoria: UPS Space University, WWW.up.ac.az/dspace/handle.net; 2008.
10. Banu A, Ali Y, Muammer K, Bülent S, Selman Ç, Enis U. Sex determination by the interarticular distance of metacarpals and phalanges: a digital radiologic study in contemporary Turkish people. *Anatomy* 2009;**3**:14–20.
11. Tanuj K, Pradeep KG, Ritesh GM. Index and ring finger ratio. A new sex determinant in south Indian population. *For Sci Int* 2008;**181**(1):53e1–4.
12. Kanchan T, Pradeep KG, Ritesh GM. Index and ring finger ratio new sex determinant in south Indian population. *For Sci Int* 2008;**181**(1):53.e1–4.
13. Sotiris KM, Constantine E, Christos GK, Sherry CF. Sex determination using metacarpal biometric data from the Athens collection. *For Sci Int* 2009;**193**(1):130.e1–6.
14. Zakaria MS, Aly HM, Sahar RH, Morid MH, Ayman LF. Calcaneus radiograph as a diagnostic tool for sexual dimorphism in Egyptians. *J for Leg Med* 2010;**17**(7):378–82.
15. Groves AM, Cheow H, Balan K, Courtney H, Bearcroft P, Dixon A. 16-MDCT in the detection of occult wrist fractures: a comparison with skeletal scintigraphy. *AJR* 2005;**184**:1470–4.
16. Steyn M, İscan A. Metric sex determination from the pelvis in modern Greeks. *For Sci Int* 2008;**179**(86):1–6.
17. Paola M., Stefano D., Inmaculada A. and Miguel C. : Sex assessment from the carpals bones: discriminant function analysis in a 20th century Spanish sample. For Sci Int 2011;**206**(1–3):216.e1–10.
18. Kewal K, Tanuj K, Abhilasha S. Sex determination from hand and foot dimensions in a North Indian population. *J For Sci*; 2011. Article online in advance of press.
19. Tanuj K, Pradeep GK. Index and ring finger ratio- a morphologic sex determinant in South-Indian children. *For Sci Medicine Pathol* 2010;**6**(4):255–60.
20. Smith SL. Attribution of hand bones to sex and population groups. *J For Sci* 1996;**41**:469–77.
21. Goncharova NN, Samokhodskaia OV, Fedulova MV, Pigolkin IuI, Pavlovskiĭ OM, Batsevich VA, et al. Identification of human gender by hand x-ray. *Sud Med Ekspert* 2005;**48**(5):21–6.
22. Robertson J, Zhang W, Liu JJ, Muir KR, Maciewicz RA, Doherty M. Radiographic assessment of the index to ring finger ratio (2D:4D) in adults. *Anat* 2008;**212**(1):42–8.
23. Soren B, Shelley R, Marnie J. Disaster victim identification: new applications for postmortem computed tomography. *J For Sci* 2008;**53**(4):956–61.
24. O'Donnell C, Iino M, Mansharan K, Leditscke J, Woodford N. Contribution of postmortem multidetector CT scanning to identification of the deceased in a mass disaster: experience gained from the 2009 Victorian bushfires. *For Sci Int* 2011;**205**:15–28.
25. Filograna L, Bolliger SA, Ross SG, Ruder T, Thali MJ. Pros and cons of postmortem CT imaging on aspiration diagnosis. *J Leg Med* 2011;**13**(1):16–21.
26. Filograna L, Tartaglione T, Filograna E, Cittadini F, Oliva A, Pascali VL. Computed tomography (CT) virtual autopsy and classical autopsy discrepancies: radiologist's error or a demonstration of post-mortem multi-detector computed tomography (MDCT) limitation? *For Sci Int* 2010;**195**(1–3):e7–13.
27. Selma U, Nursel T, Anil N, Dilek G, Ritesh G, Mahmut K, et al. Sex determination from measurements of the sternum and fourth rib using multislice computed tomography of the chest. *For Sci Int* 2010;**197**(1):120e1–5.
28. Uysal S, Gokharman D, Kacar M, Tuncbilek I, Kosa U. Estimation of sex by 3D CT measurements of the foramen magnum. *J For Sci* 2005;**50**(6):1310–4.
29. Frank R, Mattias K, Axel G, Verhoff MA. Digital forensic osteology: morphological sexing of skeletal remains using volume-rendered cranial CT scans. *For Sci Int* 2010;**195**(1):148–52.
30. Prokop M. MDCT: technical principles and future trends. In: Marchal G, Vogl TJ, Heiken JP, Rubin GD, editors. *Multidetector-row computed tomography scanning and contrast protocols*. Springer-Verlag Italia; 2005. p. 5–12.
31. Kalra MK, Saini S. Practical approach to MDCT. In: Saini S, Rubin GD, Kalra MK, editors. *MDCT: a practical approach*. Springer-Verlag Italia; 2006. p. 3–9.
32. Bone HM, Jäger L, Frei KA, Galiano S, Srivastav SK, Flohr T, et al. Optimization of MDCT of the wrist to achieve diagnostic image quality with minimum radiation exposure. *AJR* 2005;**185**:647–54.
33. Iscan MY, Miller SP. Sexual dimorphism in the femur and tibia. In: Reichs KJ, editor. *Forensic osteology. Advanced in the identification of human remains*. 11th ed. USA: Charles C. Thomas, Springfiled; 1986. p. 102–11.
34. Tanuj K, Kewal K. Anthropometry of hand in sex determination of dismembered remains - a review of literature. *J For Leg Med* 2011;**18**(1):14–7.
35. Case DT, Rose AH. Sex determination from hand and foot bone lengths. *J For Sci* 2007;**52**(2):264–70.
36. Dibennardo R, Taylor JV. Classification and misclassification in sexing the black femur by discriminant function analysis. *Am J Phys Anthropol* 1982;**70**:3–9.
37. Ruff C. Sexual dimorphism in human lower limb bone structure: relationship to subsistence strategy and sexual division of labor. *J Hum Evol* 1987;**16**:391–416.
38. Black TK. A new method for assessing the sex of fragmentary skeletal remains: femoral shaft circumference. *Am J Phys Anthropol* 1978;**48**:227–32.
39. Scheuer JL, Elkington NM. Sex determination from metacarpals and the first proximal phalanx. *J for Sci* 1993;**38**(4):769–78.
40. Falsetti AB. Sex assessment from metacarpals of the human hand. *J For Sci* 1995;**40**(5):774–6.
41. Calhoun PS, Kuszyk BS, Heath DG, Carley JC, Fishman EK. Three-dimensional volume rendering of spiral CT data: theory and method. *RadioGraphic* 1999;**19**:745–64.
42. Kaewlai R, Avery LL, Asrani AV, Abujudeh HH, Sacknoff R, Novelline RA. Multidetector CT of carpal injuries: anatomy, fractures, and fracture-dislocations. *RadioGraphic* 2008;**28**:1771–84.
43. Kalayci I. 3D reconstruction of phalangeal and metacarpal bones of male judo players and sedentary men by MDCT images. *J Sports Sci Med* 2008;**7**:544–8.